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LIGHTWEIGHT ZERODUR MIRROR TECHNOLOGY
TECHNICAL REPORT ANALYSIS CONDENSATION EVALUATION (TRACE)

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Design tradeoffs for large passive High Energy Laser (HEL) mirrors have shown that Zerodur Glass-Ceramic is an attractive alternative to ULE glass because of its low coefficient of thermal expansion (CTE), greater homogeniety, and easier machinability and polishability. Zerodur has not been selected as a candidate mirror blank material because the technology for producing lightweight mirrors from Zerodur did not exist. Schott Glaswerke recently began developing the techniques required for the fabrication of lightweight Zerodur mirror blanks. The objective of this program was to assess the potential of Zerodur for use as a large lightweight passive mirror material in terms of properties, producibility, and performance by 1) demonstrating the technologies for fabricating mirror blanks; 2) obtaining property data on fabricated Zerodur mirror parts; 3) investigating manufacturing processes applicable to the production of lightweight Zerodur blanks; and 4) analytically predicting the performance of a lightweight Zerodur mirror under high front surface thermal loading. Areas of technology requiring further development were identified.

A subcontract was awarded to Schott Glaswerke (through Schott Optical Glass in Duryea, Pa.) to demonstrate the blank fabrication techniques, measure various physical properties of the fabricated parts, and to perform an in-depth manufacturing study to select the optimal processes and to estimate the cost and schedule to scale the processes to the production of large mirror blanks. Schott also prepared cost and schedule estimates for programs to complete the technology development effort.

Samples prepared by Schott were evaluated by Perkin-Elmer for workmanship and uniformity. Verification of the strength values reported by Schott were obtained by tensile testing some of the samples. All of the data obtained from the property measurement program were evaluated against the properties required for successful operation of a large lightweight passive mirror.

The performance of a Zerodur mirror under high front surface thermal loading was analytically predicted using finite element methods. The performance of this mirror was compared to ULE mirror of the same configuration. The design of the Zerodur mirror was optimized for maximum thermal bending rigidity and the performance of this mirror was determined.

The proposed Zerodur mirror consists of two curved facesheets frit bonded to a hexagonal celled eggcrate type core. Schott prepared core samples by bending Zerodur glass to form half hexagons and subsequently welding the half hexagons into a hexagonal lightweight core. The core would be annealed, ceramized, and generated to the required curvature. Measurements performed on samples yielded bending strengths of over 3400 PSI (average). The bending and welding processes were found to have a negligible effect on the thermal expansion behavior of the Zerodur. Semiautomatic machines for performing these operations were built and successfully tested during this program.

Processes for the efficient production of thin curved facesheets were also investigated. The most promising technique is the slumping of flat Zerodur glass plates in polished metal molds. This process was demonstrated on a laboratory scale and should be scaleable to large sizes. The advantage would be efficient utilization of material and near-net shape fabrication which would reduce the cost and time required for generating. Spin casting was investigated as an alternative to slumping for the near net shape production of facesheets.

Schott demonstrated the use of a frit bonding agent for fastening the facesheets to the lightweight cores. Measurements indicate that the coefficient of thermal expansion of the frit closely matches that of Zerodur in the range of operation of the mirror. The bending strength of the fritted joints exceeds the minimum requirements for a lightweight mirror structure.

The thermal performance of a lightweight Zerodur mirror having the same design as the Kodak 4 meter ULE mirror was predicted using finite element techniques. The performance of the Zerodur mirror was found to be superior to that of the ULE mirror because of the greater thermal conductivity, specific heat, and mass density of the Zerodur. The Zerodur mirror was heavier (3180 lbs. vs. 2780 for the ULE mirror) due to the higher density of the Zerodur. An optimization of the design of the Zerodur mirror was performed by varying the faceplate thickness, backplate thickness, and core height to maximize the thermal bending rigidity. A mirror having a total weight of 2500 lbs. was designed and the thermal performance of this mirror was calculated.

The rms distortions for this mirror after 100 seconds of HEL exposure were $\lambda/124$ and $\lambda/1338$ before and after focus correction, respectively. The analysis showed that the properties of Zerodur and fritted and welded Zerodur joints are adequate for the successful operation of a lightweight Zerodur mirror.

A detailed manufacturing study was performed to evaluate the scaleability of the techniques developed by Schott for the fabrication of mirror blanks up to 4 meters in diameter. The study concluded that the processes are scaleable. Schott prepared estimates for the cost and schedule to establish a facility for the production of 4 meter mirror blanks. Schott also identified several specific areas which require further development work. The cost and schedule for completing the development of the frit bonding technology was estimated. A proposal has been prepared which is designed to complete the technology development for the slumping process. Proposals have also been prepared for the fabrication and testing of demonstration blanks up to 1.5 meters in diameter.